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Overview properties of biodiesel diesel blends from edible and non-edible feedstock

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ABSTRACT

Biodiesel is biodegradable and nontoxic alternative fuel for diesel engine which has become more attractive to replace diesel fuel. In this study, vegetable oil was identified as potential sources for biodiesel production. The production of biodiesel from different non-edible oilseed crops has been extensively investigated for the past few years. Thus, the aim of this study is to critically review on the characteristic of the potential biodiesel and biodiesel diesel blends fuel properties. The aspects of this study cover the biodiesel production and fuel properties of biodiesel and biodiesel blends. Besides, some studies have shown that there is a direct correlation between fatty acid composition and biodiesel properties. The fuel properties of biodiesel blends fuel were very close to diesel fuels and satisfied ASTM 6751 and EN 14214 standards. As a final note, further study on the utilization of biodiesel blends needs to be carried out in order to ensure optimization in engine operation.

Contents

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1. Introduction

Energy has become a key to boost the economic development across the world. Although the fossil fuels are limited and non-renewable, nevertheless the demand of these resources are increasing rapidly [1]. Fossil fuel depletion and environmental degradations are predicted to become the biggest problem in the future. Due to these problems, there is a need to enhance energy security and mitigation of GHGs emissions. Thus, there is an urgent need to find alternative renewable energy resources that are clean, sustainable, reliable, and economical feasible. Biodiesel is one of the solutions that have been considered to solve the problem of fossil fuel depletion and environmental degradation [2,3].

Investigation of biodiesel (methyl ester) produced from vegetable oils, animal fats, or waste cooking oils were carried out by many researchers. Palm biodiesel is predominantly used in Asia, while soybean is used in United State and canola biodiesel is dominant in Europe [4,5]. However, the edible oil based biodiesel faced the high price of the feedstock and competition between food and fuel. Nevertheless, biodiesel can be produced from other feedstocks such as non-edible oil, microalgae and animal tallow [1,6,7]. Non-edible feedstock like *Jatropha curcas*, *Calophyllum inophyllum*, *Nicotiana tabacum* and *Hevea brasiliensis* usually have high free fatty acid which required pretreatment production process [8–12]. Biodiesel has different chemical composition from the petroleum diesel fuel and contains about 10% of oxygen by weight. Biodiesel has higher density, viscosity, cloud point, lower volatility and heating value compared to commercial grades of diesel fuel. On top of that, biodiesel does not contain any sulfur, aromatic hydrocarbons, metals and crude oil residues [1,6,13–16].

In addition, biofuel is can be completely mixed with petroleum diesel and the blending of these two fuels allow in any proportion. Biodiesel can be used blended with diesel in existing compressed ignition engines without modifications to the engine [4,17–19]. Furthermore, it is important to know the properties of biodiesel diesel blends. Biodiesel blended with diesel will bring many beneficial characteristics to the diesel engine. Thus, this study will focus on the critical review of potential biodiesel production from edible oil (palm oil or refining palm oil and *Alureitas moluccana*) and non-edible oil (*J. curcas, Sterculia foetida, C. inophyllum, Ceiba pentandra, Pangium edule, H. brasilienesis* and *Cerbera manghas*). Besides, the detail characteristic properties of biodiesel and its blends were evaluated.

2. Feedstock for biodiesel production

Globally, there are more than 350 oil-bearing crops identified as potential sources for biodiesel production [1,20–22]. Vegetable oil based biodiesel which from renewable sources has become more attractive recently due to their environmental benefits. Moreover, edible oil (palm oil) has high production rate and high oil content to meet the future energy demand [23]. Besides, non-edible vegetable oils or second generation feedstock are also considered as prospective feedstocks for biodiesel production. The wide range of available feedstock for biodiesel production represents one of the most significant factors for biodiesel production [1,24]. The feedstock should fulfill two main requirements which are low production costs and large production scale. The availability of feedstock for biodiesel production depends on the regional climate, geographical locations, local soil conditions and agricultural practices of any country [1,6,25]. Fig. 1 shows several biodiesel feedstocks in selected countries around the world.

2.1. Edible oil

2.1.1. Palm oil (Elaeis guineensis)

Oil palm was classified as *Elaeis guineensis* native to the West Africa was grown in wild and later developed into an agricultural crop [15,24,26]. The oil palm is a tropical perennial plant and grows well in lowland with humid places. Therefore, it can be cultivated easily in Malaysia, Indonesia and Thailand [4,15,24,26]. The tree is unbranched and single-stemmed which can grow up to 20–30 m in height. The cultivated oil palm carries fruit from the fourth year onward and can be harvested for 40–50 years. The fleshy orange reddish coloured fruits were grown in large and tight female bunches containing up to 2000 fruitlets [24,27]. Oil palm is high oil yield crop producing on average about 4–5 t of oil/ha annually which is about 10 times the yield of soybean oil [28]. Crude palm oil is semisolid at room temperature. Palm kernel oil is rich in lauric and myristic fatty acid with an excellent oxidative stability and sharp melting [23].

2.1.2. Aleuritas moluccana

Aleurites moluccana (L.) also known as candlenut, is one of the world's greatest domesticated multipurpose trees. It is native to Malaysia, Indonesia, Philippines and South Pacific islands including Hawaii. The *A. moluccana* trees can grow very well in tropical climates with ample rainfall and also adaptable to dry climates [29]. The productivity of *A. moluccana* fruit yields vary from 4 mt/ha to 20 mt/ha and oil yield is around 3100 kg/ha annually [30]. *A. moluccana* seed contains around 30% of oil and 15% free fatty acid with high iodine number [29,31]. The oil derived from the seeds provide material for lighting, cooking, resin, pharmaceuticals, and cosmetics production [29–31].

2.2. Non-edible oil

2.2.1. Jatropha curcas

J. curcas L. is a small tree or large shrub up to 5–7 m tall belonging to the Euphorbiaceae family [22,32–36]. *J. curcas* is

Nomenclature

B10	10% biodiesel blend with 90% diesel
B20	20% biodiesel blend with 80% diesel
B30	30% biodiesel blend with 70% diesel
CAMO	Crude *Aleurites moluccana* oil
CCIO	Crude *Calophyllum inophyllum* oil
CCPO	Crude *Ceiba pentandra* oil
CCMO	Crude *Carbera manghas* oil
CHBO	Crude *Hevea brasiliensis* oil
CIB	*Calophyllum inophyllum* blending
CIB10	*Calophyllum inophyllum* blending 10%
CIB20	*Calophyllum inophyllum* blending 20%
CIB30	*Calophyllum inophyllum* blending 30%
CIME	*Calophyllum inophyllum* methyl ester
CJCO	Crude *Jatropha curcas* oil
CMME	*Cerbera manghas* methyl ester
CMB	*Cerbera manghas* blending
CMB10	*Cerbera manghas* blending 10%
CMB20	*Cerbera manghas* blending 20%
CMB30	*Cerbera manghas* blending 30%
CPB	*Ceiba pentandra* blending
CPB10	*Ceiba pentandra* blending 10%
CPB20	*Ceiba pentandra* blending 20%
CPB30	*Ceiba pentandra* blending 30%
CPME	*Ceiba pentandra* methyl ester
CPO	Crude palm oil
CSFO	Crude *Sterculia foetida* oil
HBB	*Hevea brasiliensis* blending
HBB10	*Hevea brasiliensis* blending 10%
HBB20	*Hevea brasiliensis* blending 20%
HBB30	*Hevea brasiliensis* blending 30%
HBME	*Hevea brasiliensis* methyl ester
JCB	*Jatropha curcas* blending
JCB10	*Jatropha curcas* blending 10%
JCB20	*Jatropha curcas* blending 20%
JCB30	*Jatropha curcas* blending 30%
JCME	*Jatropha curcas* methyl ester
PEME	*Pangium edule* methyl ester
PME	Palm methyl ester
SFME	*Sterculia foetida* methyl ester
SFB	*Sterculia foetida* blending
RPME	Refine palm methyl ester
RPMEB	Refine palm methyl ester blending
RPMEB10	Refine palm methyl ester blending 10%
RPMEB20	Refine palm methyl ester blending 20%
RPMEB30	Refine palm methyl ester blending 30%

considered as one of the most promising potential oil source to produce biodiesel in Asia, Europe and Africa. *J. curcas* is capable to survive in abandoned and fallowed agricultural land [25,35,37,38]. *J. curcas* is grown in marginal and waste lands with no possibility of land use competing with food production. Various parts of *J. curcas* plant have medicinal values. Apart from supplying oils for biodiesel production, the growing of the tree itself effectively reduces CO_2 concentrations in the atmosphere. It has been identified as the major source of nonedible oil biodiesel in developing countries like Indonesia, Malaysia and India. The oil yields of *J. curcas* is reported to be 1590 kg/ha [22,25,35,39–41]. According to No studies [42] the oil content of *J. curcas* seeds is 20–60% and 40–60% of oil in kernels.

2.2.2. *Sterculia foetida*

S. foetida L. plant belongs to sterculiaceae family classified as non-drying oils. It is a wild plant and well adapted in tropical and sub-tropical area (30°North Latitude – 35° South Latitude). The plant has an average life span of more than 100 years [43–45]. *S. foetida* is a large evergreen tree found usually in the western and southern parts of India, Burma, Malaysia and North Australia [46,47]. *S. foetida* is a large, straight, deciduous tree growing up to 40 m in height and 3 m in girth, with the branches arranged in whorls and spreading horizontally [20,48]. The seed oil can be used for culinary purposes but is frequently used as an illuminant; other possible uses are in the medicine industry, soap-making industry and surface-coating industry [46,49,50]. The kernel of the seeds consist 50–60% of light-yellow fatty oil yield [46]. According to Bureau of Plant Industry research [50], the main compositions of *S. foetida* dry shelled seeds are fats (51.78%), protein (21.61%), starch (12.1%), sugar (5%), cellulose (5.51%) and ash (3.9%). Based on Kale et al. study [49], the fatty acids found in the oil were oleic acid (20.50%), linoleic acid (12.86%), palmitic acid (11.87%), sterculic acid (6.76%) and margaric acid (2.28%).

2.2.3. *Calophyllum inophyllum*

C. inophyllum L. commonly known as polanga or honne, is a non-edible oil seed belongs to the Clusiaceae family. This plant has multiple origins including East Africa, India, South East Asia and Australia [10,25,38,40,52]. The fruit is reported to be pinkish–green at first, and it turns to be bright green when ripe. The tree yield is around 100–200 fruits/kg [53,54]. The seed is surrounded by a shell and a thin layer of pulp of 3–5 mm. Traditionally, *C. inophyllum* oil has been used as a medicine, soap, lamp oil, hair grease and cosmetic in different parts of the world. According to Venkanna and Reddy study [52], the kernels have very high oil content which is around 75% of dark green oil. *C. inophyllum* seed oil is considered as one of the potential non-edible feedstock for biodiesel production. The fuel properties of *C. inophyllum* biodiesel were found to be comparable to both the ASTM and European standards [10].

2.2.4. *Ceiba pentandra*

C. pentandra L. Gaertn or locally known as kekabu and kapok belongs to the Malvaceae family [55]. It was native to Southeast Asia and cultivated in Southeast Asia, India, Sri Lanka and tropical America [56,57]. It was grown naturally in humid and sub humid tropical region. *C. pentandra* is generally drought-resistant tree and pods from these trees are leathery, ellipsoid and pendulous capsule [58]. *C. pentandra* seeds occupy about 25–28% (w/w) of oil in each fruit [59]. The average oil seed yield was around 1280 kg/ha. *C. pentandra* seeds have low feeding value due to the higher fiber content. Moreover, the possibility of *C. pentandra* fiber as bioethanol feedstock has been investigated by Tye et al. [60]. Their study found that *C. pentandra* fiber contains 34–64% of cellulose and has high potential to produce cellulosic ethanol. Traditionally, kapok fibers are utilized as stuffing material for beds and pillows [61]. *C. pentandra* contains a pair of unique cyclopropene fatty acids (malvalic acid) which are more reactive than polyunsaturated carbon bond in the reaction by atmospheric oxygen. Thus, this hydrocarbon chain reduces oxidation stability in *C. pentandra* oil [62]. Bindhu et al. [63] reported that cyclopropene fatty acids (malvalic acids) lead to increased viscosity and caused oxidation faster than palmitic acid.

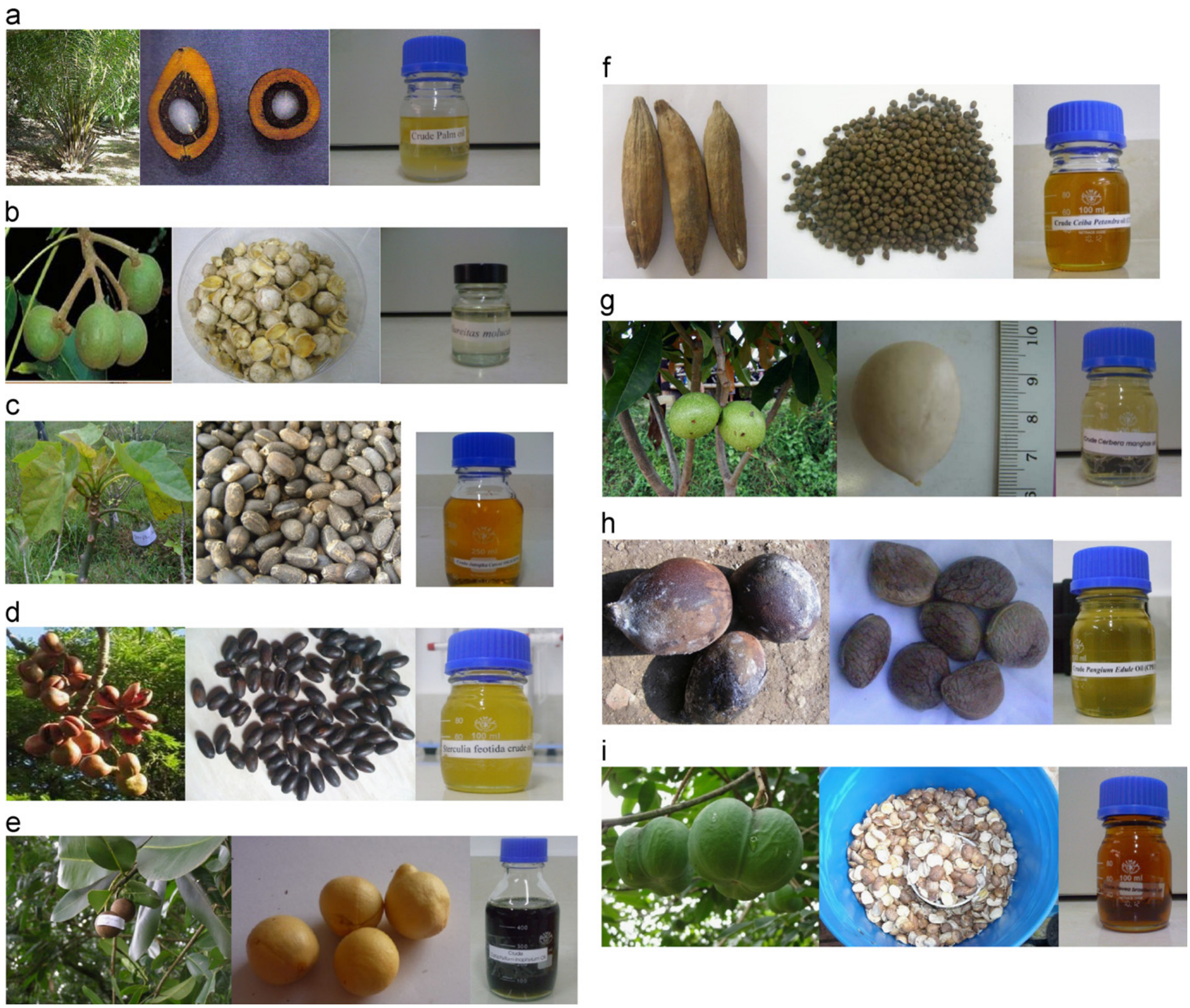


Fig. 1. The edible and non-edible feedstock: (a) palm oil (*E. guineensis*), (b) *Alurietas mollucana*, (c) Jatropha *curcas*, (d) Sterculia *foetida* (e) *Calophyllum inophyllum*, (f) Ceiba *pentandra*, (g) Cerbere *manghas*, (h) Pangium *edule*, (i) *Hevea brasilinensis*.

2.2.5. *Pangium edule*

P. edule belongs to Salicaceae family and also known as football fruit. It is native to the mangrove swamps of Southeast Asia (Indonesia, Malaysia and Papua New Guinea). It is a medium to large tree with large, glossy and heart-shaped leaves. The fruit is oval and about the size of a large husked coconut, brown and rough-surfaced. The matured fruit is edible but the seeds are extremely poisonous and should not even be tasted [64]. According to Andarwulan et al. [65], Puspitasari et al. [66] and Angryani [67] reported that the dominant fatty acid composition were oleic (23.89%) and linoleic acid (20.75%). Besides, the seeds contain 21–27% of oil which did not contain polyunsaturated carbon (cyclopentenyl fatty acids) which can enhance the oxidative stability of oil [65]. Therefore, *P. edule* oil has high antioxidant which is important in the quality of biodiesel. However, very little research has been done on biodiesel production from this oil.

2.2.6. *Hevea brasilienesis*

H. brasiliensis (rubber tree) is a perennial plantation crop belongs to the Euphorbiaceae family, originated from South America and cultivated in tropical climatic regions. [68]. The rubber tree grows most rapidly at altitudes below 200 m and monthly mean temperatures about 28 °C [69]. The natural rubber producers in the world are Thailand (35%), Indonesia (23%), Malaysia (12%), India (9%), and China (7%) [70]. Rubber tree seed contain 50–60% of oil and kernel contain 40–50% of brown colour oil [9,71]. Ramadhas et al. [68] reported that rubber seed oil consists 18.9% of saturated fatty acid (palmitic and stearic acids) and 80.5% unsaturated fatty acid (mainly of oleic, linoleic and linolenic acids). Saturation fatty acids will increase the cloud point, cetane number and improve oxidation stability. Moreover, Ikwuagwu et al. [9] investigated that rubber biodiesel has closer fuel properties with diesel fuel except slightly higher in viscosity.

2.2.7. *Cerbera manghas*

Cerbera odollam (sea mango) also called *C. manghas* L. is a tree belonging to the poisonous Apocynaceae family [72]. *C. manghas* grows well in coastal salt swamps and creeks as well as along the riverbanks such as in south India, Vietnam, Cambodia, Myanmar and Malaysia [25,72,73]. The *C. manghas* tree grows to a height of 6–15 m and has dark green fleshy lanceolate leaves. The fruit looks like a small mango with a green fibrous shell enclosing an

ovoid kernel [25,72]. The oil content from *C. manghas* seeds is 54%. The fatty acid composition of *C. manghas* oil are mainly from oleic (48.1%), followed by palmitic (30.3%), linoleic (17.8%) and stearic (3.8%) [25,73].

3. Biodiesel production

Biofuels derived from various sources such as vegetable oils and fats uses different production processes as feedstock. The biodiesel production is carried out by using alcohol and catalyst via transesterification process with vegetable oil or fat oil [8,35,74,75]. The catalyst presence is necessary to increase the reaction rate and the transesterification reaction yield. The main catalysts used are alkaline catalysts (NaOH and KOH) as NaOH and KOH catalysts are easily soluble in methanol to form sodium and potassium methoxide. The advantage of this process is it has high yields under mild conditions and the reaction takes shorter time to complete the process [76]. Karmee and Chadha [77] prepared biodiesel from the *Pongamia pinnata* by transesterification in the presence of potassium hydroxide as catalyst. The maximum conversion oil was 92% of methyl ester using 1:10 molar ratio of oil to methanol at 60 °C. The viscosity and flash point of biodiesel obtained were 4.8 cSt and 150 °C. Ramadhas et al. [68] studied biodiesel production from high free fatty acid rubber seed oil. They developed a two-step transesterification process to convert the high free fatty acid oils to biodiesel. The viscosity of rubber biodiesel is slightly higher than diesel (5.81 mm^2/s) and the calorific value is about 14% (36.50 MJ/kg) less than diesel. Wang et al. [78] studied the optimization of biodiesel production from *Datura stramonium* using a two-step catalyzed process (acid-catalyzed followed by base-catalyzed). The maximum FAME yield obtained is 87% and more than 98 wt% FAME content. Furthermore, the fuel properties of *D. stramonium* biodiesel produced fulfilled the ASTM biodiesel standard. Besides, Vennkanna and Reddy [52] discussed the three stage process which is pre-treatment, alkali catalyzed transesterification and post treatment for biodiesel production and optimization of *C. inophyllum* linn oil (honne oil). However, the acid value of honed oil was reduced from 4.76 mg KOH/g to 1.64 mg KOH/g during acid esterification reaction and yield of biodiesel under the optimized conditions is found to be 89%. On the other hand, Patil and Deng [79] concluded that most of the non-edible oil needs a two-step transesterification process which are acid esterification and alkali transesterification to obtain high biodiesel yield.

4. Influence of fatty acid composition on biodiesel properties

The major components of biodiesel fuels are straight chain fatty acids and the common fatty acid are palmitic (hexadecanoic) acid, stearic (octadecanoic) acid, oleic (octadecenoic) acid, linoleic (octadecadienoic) acid and linolenic (octadecatrienoic) acid [80]. Various studies on characterization properties of biodiesel have suggested that biodiesel with a high level of methyl oleate (monounsaturated fatty acid) may have excellent characteristics in ignition quality, fuel stability and flow properties at low temperature [38]. The influence of fatty acid composition structure on biodiesel properties have been demonstrated in several studies. Some studies show that there are direct correlation between the fatty acid composition and biodiesel properties. The presence of sterculic and malvalic acid in *S. foetida* oil have a negative effect on the auto-oxidation of biodiesel [63]. However, the high percentage of fatty acids makes *H. brasiliensis* more susceptible to oxidation than other nonedible oils [9]. Pinzi et al. [38] reported that antioxidants additive and transgenic methods have been used to reduce particularly polyunsaturated fatty acid present in the crude oil; and can improve oxidation stability. Some authors have found that saturated chain (capric acid) is suitable for cold flow properties and possess higher oxidative stability [38,81,82] due to long saturated chain and the absence of double bounds [5]. Fatty acid composition will affect the iodine value whereas the higher iodine value leads to rapid deterioration of lubricant oil [17,82]. Generally, non-edible oil composed by high number of double carbon chain (polyunsaturated acid) indicated that non-edible oil have a greater degree of unsaturated fatty acid than saturated carbon chain acid [83]. Therefore, this structural fatty acid composition will influence the physicochemical properties of biodiesel such as cetane number, heat of combustion and viscosity [20,38,80,82]. As a result, the increase of carbon chain length consequently increases the heating value and shorter the ignition delay compared to diesel fuel [81]. Moreover, the fatty acid compositions of biodiesel greatly influence cold properties. The higher saturation chain level will reduce the cloud point of biodiesel. On the other hand, the freezing point of biodiesel increases with the increase of carbon chain length and decreases with the increase of double bonds [82]. This condition is one of the most critical obstacles against the widespread of biodiesel usage. In addition, viscosity of any fuel is related to its chemical structure. Hence, viscosity increases with the increase in the carbon chain length and decreases with the increase in the number of double bonds (unsaturation chain level) [84]. The density of biodiesel from vegetable oils are denser and less compressible than diesel fuel [1,19,20,85]. The chain length of fatty acid composition raises the density of fuel [1,20,38,80,82,85]. Thus, biodiesel produced from saturated fatty acids have lower density than unsaturated acid. The influence of fatty acid composition of various vegetable oil on biodiesel properties is shown in Fig. 2.

5. Characteristics and properties of biodiesel

The biodiesel standard testing methods are American standards ASTM D6751 and European Union EN 14214 [24]. American standard ASTM D6751 identifies that the parameters of the pure biodiesel (B100) should fulfill before being used as a pure fuel or blended with diesel fuel. On the other hand, European Union EN 14214 describes the minimum requirements for FAME (fatty acid methyl ester). Biodiesel (B100) specifications ASTM D6751 and EN 14214 standards are shown in Table 1 [20,86,87] and the analyzed results are shown in Table 2.

5.1. Kinematic viscosity

Kinematic viscosity is defined as the resistance of liquid to flow. It refers to the thickness of the oil and is determined by measuring the amount of time taken for a given oil to pass through an orifice of a specified size [88]. High viscosity may lead to the formation of soot and engine deposits due to insufficient fuel atomization. On the other hand, lower viscosity is easier to pump and achieve final droplets to injector [14]. The kinematic viscosity in biodiesel was determined using by ASTM D445 (1.9–6.0 mm^2/s) and EN ISO 3104 (3.5–5.0 mm^2/s) standard method [86,87]. Demirbas and Nakpong [14,89] reported that biodiesel has viscosity close to diesel fuels. The viscosity of biodiesel decreases sharply after alkali-catalyzed transesterification process. A similar trend of kinematic viscosity found for the potential feedstock of biodiesel was shown in Table 2. From Table 2, it can be seen that HBME and SFME possess the highest kinematic viscosity which are 4.93 mm^2/s and 4.92 mm^2/s, respectively [46], while AMME has the lowest kinematic viscosity among all oils with 3.84 mm^2/s. It was observed that RPME and PME possess a lower kinematic viscosity compared to Sarin et al.

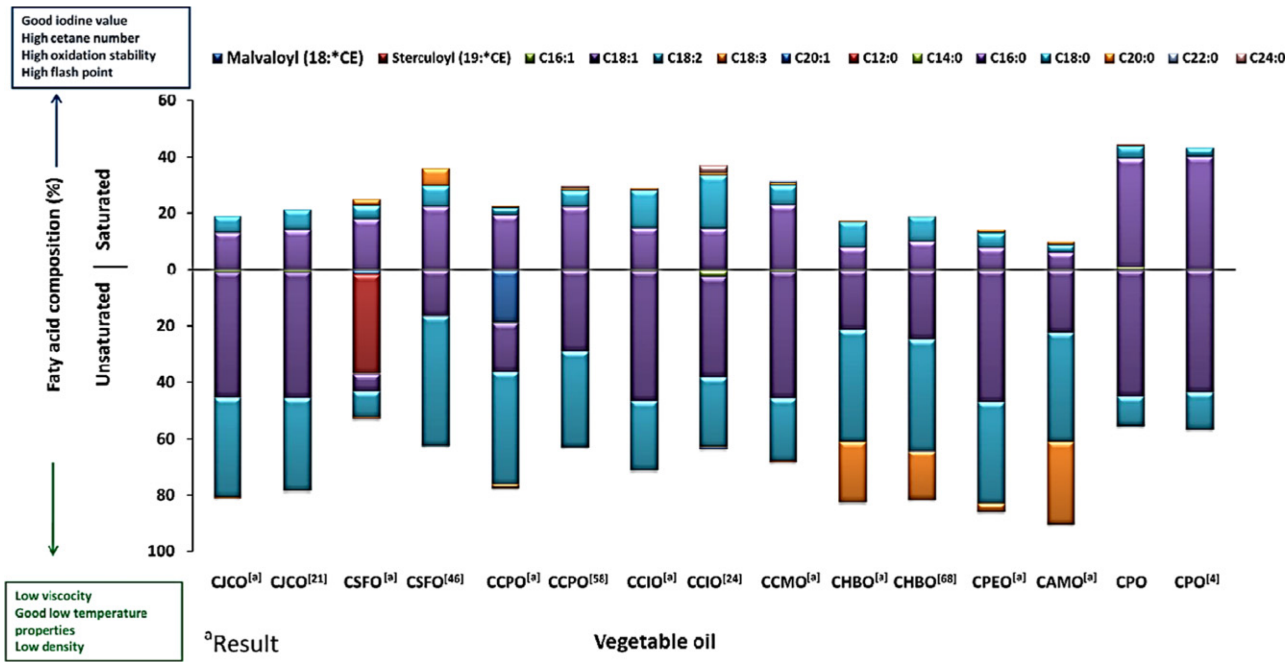


Fig. 2. Influence of fatty acid composition vegetable oil on biodiesel properties.

Table 1
ASTM D6751 and EN 14214 properties [20,86,87].

Properties	Unit	Test method		Test limit	
		ASTM	EN	ASTM D6751	EN 14214
Viscosity kinematic at 40 °C	mm^2/s	D 445	EN ISO 3104	1.9–6.0	3.5–5.0
Density at 15 °C	kg/m^3	D1298	EN ISO 3675/12185	880	860–900
Calorific value	MJ/kg	–	EN 14214	–	35
Flash point	°C	D 93	ISO DIS 3679	Min. 100–170	> 120
Pour point	°C	D 97	–	−15 to 16	–
Cloud point	°C	D 2500	–	−3 to12	–
Oxidation stability hours, 110 °C	–	D 675	EN 14112	Min. 3	Min. 6
Cetane number	–	D 613	EN ISO 5165	Min. 47	Min. 51
Acid value	mg KOH/g	D 664	EN 14104	Max.0.5	Max.0.5
Water content	%v	D 2709	EN ISO 12937	Max. 0.05	–
Canradsons carbon residue (100%)	m/m	D 4530	EN ISO10370	Max. 0.05	Max. 0.03
Sulphated ash	% m/m	D 874	EN ISO 3987	0.02	0.02

[4] which stated that viscosity of palm methyl ester was 4.5 mm^2/s. The viscosity values of palm methyl esters decrease sharply after transesterification. Generally, the viscosity of biodiesel is slightly higher compared to diesel. All the kinematic viscosity of biodiesel shown in Table 2 is within the ASTM D445 standard. The viscosity of CIME found was 4.57 mm^2/s which is slightly higher compared to Ong et al. [24] of 4.0 mm^2/s. However, JCME obtained is closer to Nagi et al. [90] study in which the viscosity of *jatropha* biodiesel was 4.84 mm^2/s. Thus, the results showed that by increasing the number of double bond has caused biodiesel to be more viscous. High values of viscosity can negatively affect the volume flow and injection spray characteristics in the engine. At low temperature, it may compromise the mechanical integrity of the injection pump drive systems. Therefore, it is suggested that these biodiesel diesel blends will improve properties fuel.

5.2. Density

Density is a physical property used to calculate the precise volume of fuel necessary to supply an adequate combustion [91]. Therefore, the effect of density in engine operation is very important to injector nozzle. This can influence the efficiency of the fuel atomization for airless combustion systems [51,92–95]. Biodiesel fuels are denser and less compressible than the diesel fuel regardless of the feedstock [82]. ASTM D1298 and EN ISO 3675/12185 test method are used to measure the density of the biodiesel [86,87]. From Table 2, it has been found that all density has complied with the ASTM and EN standard. The density of all potential biodiesel is very close which are in the range of 869.0–877.4 kg/m^3. The presence of unsaturated acid with more than two double bonds will relatively increase the density of biodiesel [23]. Sulistyo et al. [29] study show that *A. molucanna* methyl ester has higher density of 886.9 kg/m^3 at 20 °C. This slightly high density of biodiesel will leads to poor vaporization and incomplete combustion of the injected fuel [6,82].

5.3. Flash point

Flash point is the temperature at which it will ignite when exposed to a flame or a spark. Flash point varies inversely with the fuel's volatility. Generally, biodiesel have higher flash point compared

Table 2
The properties of methyl esters from various vegetable oil.

Vegetable oil methyl esters	Viscosity kinematic at 40 °C (mm^2/s)	Density at 15 °C (kg/m^3)	Calorific value (MJ/kg)	Flash point (°C)	Pour point (°C)	Cloud point (°C)	Oxidation stability hours, 110 °C
Jatropha curcas[a]	4.48	864.0	40.224	160.5	3.0	5.8	9.41
Jatropha curcas[21]	4.84	879	–	191	–	–	–
Sterculia foetida[a]	4.92	873.0	40.167	160.5	−3.0	1.2	3.44
Sterculia foetida[46]	6.0	875	40.211	162	1.0	–	–
Ceiba pentandra[a]	4.61	874.9	40.493	156.5	2.8	3.0	4.22
Calophyllum inophyllum[a]	4.57	872.5	40.204	158.5	6.0	6.0	13.08
Calophyllum inophyllum[24]	4.0	869	41.397	140	4.3	13.2	–
Pangium edule[a]	4.70	886.3	40.179	155.5	3.0	3.0	5.50
Alureitas moluccana[a]	3.84	869.0	40.127	165.5	8.0	8.0	5.31
A. molucanna[29]	4.12	886.9[b]	–	–	–	–	–
Hevea brasiliensis[a]	4.93	886.8	39.605	166.5	3.0	0.0	8.61
Hevea brasiliensis[68]	5.81	874	36.500	130	−8.0	4.0	–
Cerbera manghas[a]	4.86	869.7	40.226	159.5	6.0	8.0	8.21
Refine palm oil[a]	4.67	869.2	40.511	166.5	9.0	10	7.00
Palm oil[a]	4.45	857.0	40.511	156.5	10.5	10.5	7.50
Palm oil[4]	4.50	–	–	135	–	16	13.37
Diesel fuel	2.91	839.0	45.825	71.5	1.0	2.0	23.70

[a] Result.
[b] At 20 °C.

to diesel which is usually around 110 °C to 180 °C while conventional flash point for diesel fuel is only 55–66 °C. This means that biodiesel is safe for transport, handling and storage purpose [87]. The results from Table 2 show that HBME and RPME possess the highest flash point which are 166.5 °C, followed by AMME with 165.5 °C while PEME possess the lowest flash point of 155.5 °C. All of these biodiesel have flash point higher than 150.0 °C. According to Mofijur et al. [21], it was reported that JCME has high flash point of 191 °C. This high flash point of biodiesel is due to the presence of predominate unsaturated acid chain length of C18:1 and C18:2 in the vegetable oil [87].

5.4. Cloud point and pour point

The cloud point and pour point are important for low-temperatures applications for fuel. The cloud point is defined as the temperature at which a cloud of wax crystals first appear when the fuel is cooled. The pour point is the temperature at which the amount of wax out of solution and the fuel still can flow [1]. Therefore, higher proportions of saturated fatty acids indicate that higher pour point of biodiesel. In general, biodiesel has higher cloud point and pour point than diesel fuel [14,96]. The cloud point and pour point of nonedible biodiesel varies significantly with feedstock depending on fatty acid compositions [86,87]. From Table 2, it can observed that SFME have relatively high cloud point and pour point which are 1.2 °C and −3.0 °C, respectively, while RPME and PME possess the lowest cloud point and pour point among all biodiesels. Ong et al. [24] reported that cloud point of CIME is 13.2 °C and pour point is 4.3 °C. However, Ramadhas et al. [68] investigated that HBME has pour point of 4 °C and cloud point of −8 °C. On the other hand, biodiesel from feedstock such as *J. curcas*, *C. inophyllum*, *H. brasiliensis* have higher cloud and pour point compared to palm methyl ester due to the presence of lower fraction saturated fatty acid such as palmitic and stearic acid in the oil [87].

5.5. Oxidation stability

The oxidation of fuel is one of the important factors that help to assess the fuel quality. Oxidation stability of biodiesel is influence by factors such as presence of air, heat, traces of metal, peroxides, light, and fatty acid compound structural (presence of double bonds) [97]. In general, higher unsaturated carbon chain leads to poorer stability which the autoxidation rates depend on the number and position of the double bonds [1,23,85,97]. The Rancimat method is listed as the oxidative stability specification in ASTM D6751 and EN 14214. It can be seen from Table 2 that CIME possesses the highest oxidation stability (13.08 h) followed by HBME with 8.61 h while SFME possesses the lowest oxidation stability of 3.44 h. PME has the highest oxidation stability (13.37 h) which obtained from Sarin et al. study [4] due to PME consists because high concentrations of saturated fatty acid. Commonly, the feedstocks with high concentrations of saturated fatty acid showed better stability than unsaturated acid. Therefore, vegetable oils rich in linoleic and linolenic acids, such as *J. curcas*, *H. brasiliensis, C. manghas, P. edule* tend to have lower oxidation stability. Besides, *S. foetida* and *C. pentandra* contain cylopropene chain carbon (malvalic acid and sterculic acid) lead to increase oxidation stability and caused poor quality of biodiesel [62,63].

5.6. Calorific value

Calorific value is an important parameter in the selection of a fuel. The calorific value is not specified in ASTM D6751 and EN 14214 biodiesel standards but it is prescribed in EN 14213 (biodiesel for heating purpose) with a minimum value of 35 MJ/kg [1,20,86]. The caloric value of biodiesel is lower than diesel due to the higher oxygen content [68]. This is proved in Table 2 as the calorific values of all these feedstock are lower than diesel fuel (45.825 MJ/kg). However, it was observed that RPME and PME possess the highest calorific value of 40.511 MJ/kg followed by CPME (40.493 MJ/kg) and JCME (40.224 MJ/kg). Moreover, Devan and Mahalakshmi [46] reported that SFME has lower calorific value (40.211 MJ/kg) than diesel fuel. Besides, the calorific value of CIME reported by Ong et al. [24] is 41.397 MJ/kg. On other hand, HBME possesses the lowest calorific value of 39.605 MJ/kg and it was slightly higher compared to the results obtained from Ramadhas et al. [71] (36.50 MJ/kg).

6. Biodiesel diesel blending

Biodiesel is completely miscible with diesel and the blending in any proportion is possible in order to improve the fuel qualities. However, different chemical nature of biodiesel and diesel may cause differences in the physicochemical properties that will affect the engine performance and pollutant emissions produced [98–100]. Therefore, the researchers had investigated and studied the quality of biodiesel blends in several aspects such as properties biodiesel, blending ratio and storage time [17,18,100–102]. Currently, biodiesel diesel blends (vegetable oil methyl ester and diesel fuels) are regarded as the most widely available alternative fuel in developing countries. Therefore, the establishment of standardization for biodiesel has to be completely owned by many countries. It is utilized to protect both biodiesel consumers and producers as well as to support the development of biodiesel industries [17]. Mostly, B20 or lower blends was utilized by the biodiesel marketers and end users. Normally, the distributor will responsible for the storage, distribution and transportation to ensure the qualities of biodiesel diesel blend [103]. Furthermore, the blends up to 20% of biodiesel mixed with diesel fuels can be used in all diesel engines without modification [32,104,105].

The biodiesel diesel blends were prepared precisely by a beaker glass on a volume basis and agitation of about 2000 rpm for 15 min to ensure homogeneity. Although blend preparation on a weight basis has the advantage that weight fraction does not change with temperature, the common practice in the fuel industry is to carry out the mixing process on a volume basis at the ambient temperature of the blending location. For this reason, the option selected was using the blending ratio as a function of volumetric fractions in this work.

Characterizing the key properties of biodiesel diesel blends can assist the researchers who work on alternative fuels for diesel engines. Therefore, several different biodiesel were blended with diesel fuels up to 30% on volume basis are discussed in this study. The fuel blends were analyzed by measuring the viscosity, density, cloud point, pour point, flash point, oxidation stability and calorific value. The physical chemical tests standard and specifications of biodiesel diesel blends were shown in Table 3 [103] and Table 4 [105,106]. Furthermore, the biodiesel diesel blending results evaluated are shown in Table 5.

The flash point was at least 76 °C (137° F) which is above the minimum requirement of diesel fuel. Furthermore, the sulfur levels in biodiesel were below detectable limits for the test method specified by D975. The viscosity for all blends should not above the maximum value of 4.1 centistokes. On other hand, the methods D4539 and D6371 may be useful to estimate low temperature operability limits for vehicle when the percentage of blends is increase but it will not fulfill the standard. Therefore, by blending properly and rigorously will be ensured the properties perform satisfactorily to ASTM D975 diesel fuel standard. Furthermore, biodiesel diesel blends properties obtained is required to fulfill ASTM D975 [15,86,87,107,108].

Table 4
ASTM D7467 specification for diesel blends B6 to B20 [105,106].

Property	B6–B20 Blends	
	Test method	Limit
Viscosity (mm^2/s at 40 °C)	D445	1.9–4.1[a]
Density (kg/m^3 min.)	D1298	820
Density (kg/m^3 max.)	D6890	858
Flash point (°C, min.)	D93	52[b]
Cloud point (°C, max.)	D2500	[c]
Oxidation stability (hours, min.)	EN14112	6
Acid number (mg KOH/g, max.)	D664	0.3
Ramsbottom carbon residue on 10% bottoms (mass %, max.)	D524	0.35
Ash content (mass %, max.)	D2709	0.05
Sulfur (mg/kg max.)	D1298	10
Biodiesel content (% v/v min.)	D5453	5.1
Biodiesel content (% v/v max.)	D482	20
Water and sediment (% v/v max.)	EN 14078	0.05
Oxidation stability (hour, min.)	D445	20
Cooper corrosion (3 h at 50 °C max.)	EN 14078	Class 1

[a] The minimum viscosity shall be 1.3 mm^2/s.
[b] The minimum flash point shall be 38 °C.
[c] Low temperature properties are not strictly specified, but should be agreed upon by the fuel supplier or purchaser.

Table 5
Comparison of biodiesel/diesel blending testing.

Biodiesel/diesel blending	Viscosity (mm^2/s)	Density (kg/m^3)	Flash point (°C)	Pour point (°C)	Cloud point (°C)	Calorific value (MJ/kg)	Oxidation Stability 110 °C
JCB10	3.61	839.9	82.5	1.1	2.8	45.250	15.34
JCB20	3.75	845.2	82.5	2.0	3.6	44.249	10.20
JCB30	4.02	851.2	84.5	2.0	3.6	43.859	11.93
SFB10	3.60	841.5	82.5	−2.0	0.0	44.060	15.47
SFB20	4.00	848.5	85.5	−1.2	0.0	41.933	13.55
SFB30	4.60	857.9	87.5	1.0	1.0	40.985	11.40
CPB10	3.51	851.3	81.5	0.0	1.0	44.474	20.82
CPB20	3.58	854.0	82.5	0.0	1.9	43.150	15.82
CPB30	3.66	855.0	85.5	2.0	2.0	42.858	11.82
CIB10	3.55	851.0	77.5	0.0	4.0	42.535	25.08
CIB20	3.61	855.1	79.5	2.0	4.0	41.508	24.08
CIB30	3.78	857.9	82.5	3.0	5.0	40.479	20.08
HBB10	3.54	853.8	80.5	0.0	1.0	41.885	14.55
HBB20	3.57	854.4	82.5	1.0	1.0	41.448	13.59
HBB30	3.59	856.8	84.5	1.6	1.8	40.247	13.25
CMB10	3.43	819.2	82.5	3.5	3.0	44.292	14.33
CMB20	3.45	823.1	85.5	4.0	3.0	43.350	12.27
CMB30	3.55	836.5	88.5	4.5	3.8	41.600	10.26
RPMEB10	3.51	844.1	75.5	3.0	6.0	44.613	28.22
RPMEB20	3.58	854.0	77.5	3.0	8.0	42.483	24.07
RPMEB30	3.64	856.9	83.5	6.0	10.0	40.901	22.26

Table 3
Physical and chemical tests method of biodiesel blends [103].

Property	ASTM method	Importance
Viscosity (mm^2/s at 40 °C)	D 445	Fuel flow resistance; higher viscosity associated with poorer fuel atomization from injectors and increased engine deposits; also impacts energy requirements and wear of fuel pump and injectors
Pour point (°C)	D 97	Minimum temperature above which fuel can be poured, if still a liquid and can be pumped; affecting use in cold climates
Cloud point (°C)	D 2500	Temperature at which fuel begins to cloud, indicating wax is beginning to form (potential for plugging)
Oxidation stability	D 2274	Measure of change in fuel oil quality; indicator of "shelf life" of fuel
Cetane number	D 613	Measure of ignition delay of a compression ignition fuel; higher values indicate shorter ignition lags, fewer deposits, lower starting temperatures, reduced engine roughness

6.1. Biodiesel diesel blends viscosity

Generally, diesel fuel is less viscous than biodiesel which is shown in Fig. 3. As a result, biodiesel diesel blends of all fuels have higher kinematic viscosities as the percentage of biodiesel was increase (Table 5). This result was in agreement with Benjemea et al. [18] and Tat and Gerpen [19] mentioned that the kinematic viscosities of palm oil biodiesel diesel blends as 3.0 -4.5 mm^2/s and soybean biodiesel diesel blends as 2.8 -4.10 mm^2/s. The behavior at each blend level among the JCB, CPB, CIB, HBB, CMB, RPMEB blends did not vary significantly with regard to viscosity. For example, the kinematic viscosities of the B30 blends of CPME, CIME, HBME, CMME and RPME were 3.66 mm^2/s, 3.78 mm^2/s, 3.59 mm^2/s, 3.55 mm^2/s and 3.68 mm^2/s, respectively. Moreover, JCMEB30 has slightly higher viscosity at 4.02 mm^2/s while SFME is substantially highest at 4.60 mm^2/s. All of the blends exhibited kinematic viscosities that were satisfactory according to petro diesel biodiesel blend (ASTM D7467) standards.

6.2. Biodiesel diesel blend density

The results in Fig. 4 revealed that the densities of the biodiesel diesel blends are higher than petro diesel except CMB while SFB30 has highest density of 857.9 kg/m^3. However, CMB30 and JCB10 have density very close to petrol diesel at about 836.5 kg/m^3 and 839.9 kg/m^3. The density recorded for petrol diesel is 839.0 kg/m^3. This result matches with Alptekin and Canakci [17] which reported that the ratio blending up to 20% of six biodiesel diesel blending (sunflower, canola, soybean, cottonseed, corn oils and waste palm oil) were very close to petrol diesel. In their study, there is no significant difference among the density of the blends with up to 20% of methyl esters. The maximum difference is about 0.97% and 1.24% for the density of biodiesel diesel blends. However, Hoekman et al. [97] reviewed that density of twelve biodiesel are slightly higher than petro diesel. The density for all biodiesel diesel blends are within the recommended specified limits for biodiesel fuels by ASTM D6751 (875–900 kg/m^3) and EN 14214 (860–900 kg/m^3).

6.3. Biodiesel diesel blend flash point

Flash point is a measure of flammability of fuels and thus an important safety criterion in transport and storage. The flash point of petro–diesel fuels is only about half the value of those for biodiesels which therefore represents an important safety asset for biodiesel [15]. Fig. 5 shows that the flash point of all biodiesel diesel blends are higher than petrol diesel. The average flash points for all biodiesel diesel blends are about 82.59 °C, showing an increase of 13.42% from diesel fuel. This is agree with Shang et al. [109] which determined the flash point of Tung oil biodiesel blends are much more higher than diesel fuels. RPMEB10 has lowest flash point (75.5 °C) while CMB30 has highest flash point of 88.5 °C which is relatively higher than the ASTM D7467 specified minimum of 52 °C. This is shows that the main advantage of biodiesel diesel blends makes it possible to store and safer to handle for transportation sector. The most common blend is a mix of 20% biodiesel with 80% diesel fuel, or B20 in recent scientific investigations. However, in Europe the current regulation foresees a maximum 5.75% biodiesel [14].

6.4. Biodiesel diesel blend pour point

In general, biodiesel have higher pour points than diesel fuel and this is one of the most critical obstacles against the wide-spread of biodiesel usage [5,27,110]. The fatty acid composition of biodiesel greatly influences the pour point. However, the freezing point of biodiesel fuel increases with increasing carbon atoms in the carbon chain and decreases with increasing double bonds [1,20,25,111]. Biodiesel blends from saturated chain have higher pour points compared to unsaturated acid. Fig. 6 represents the pour point for all biodiesel blends. The higher pour point was found to be SFB10 (-2.0 °C) and SFB20 (-1.2 °C). However, RPME and CMB possess to the lowest pour point which ranges from

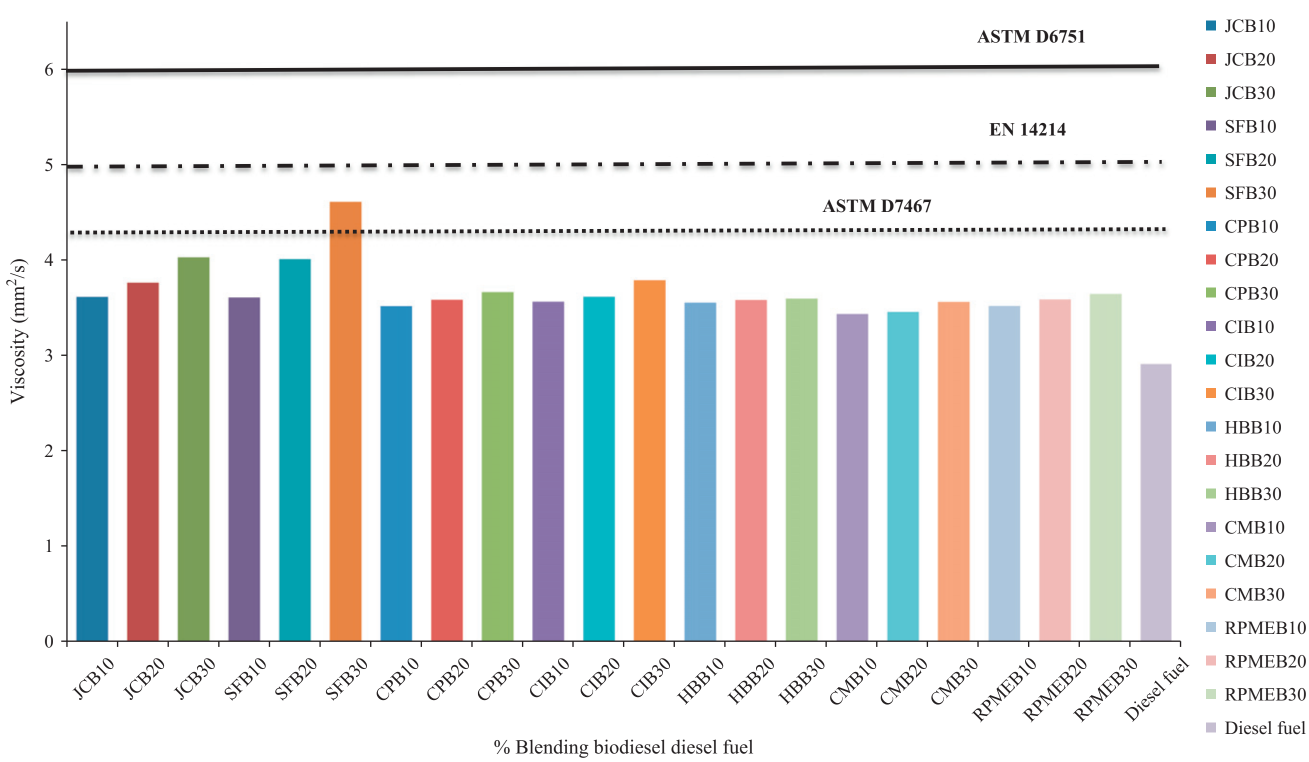


Fig.3. Viscosity biodiesel diesel blends.

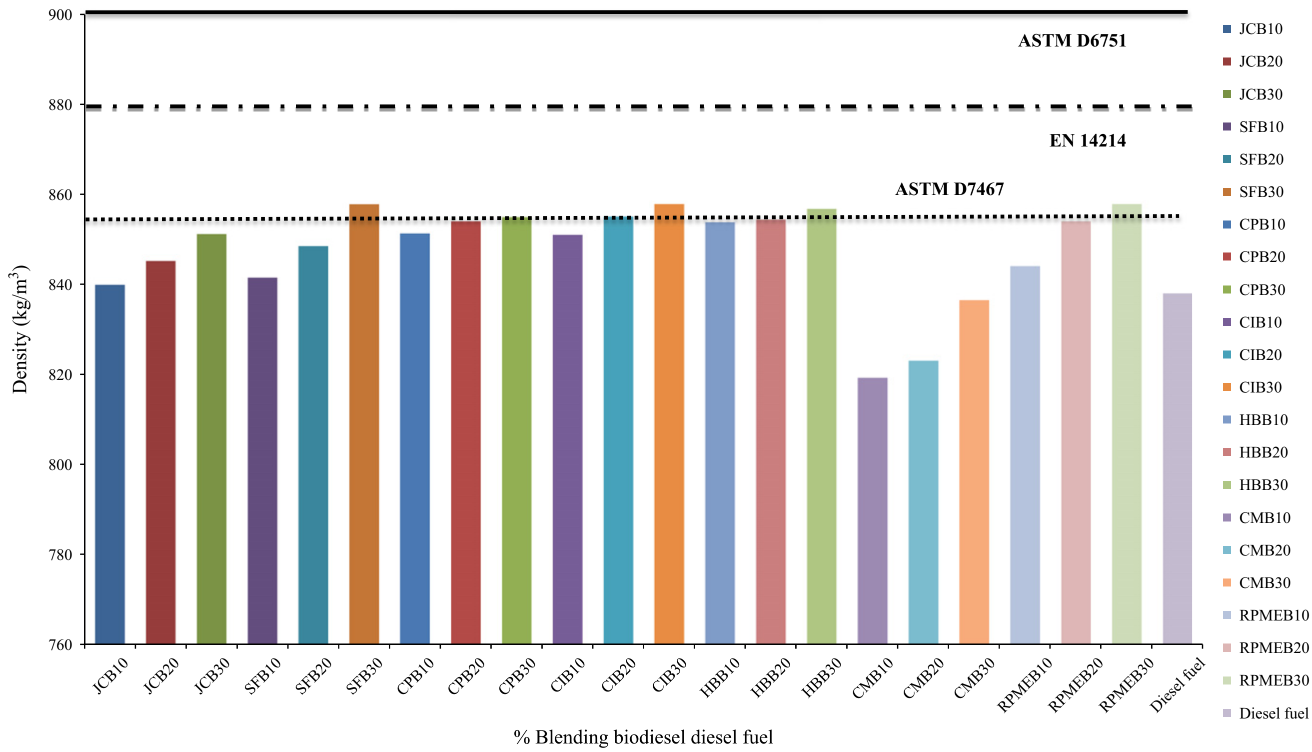


Fig. 4. Density of biodiesel diesel blends.

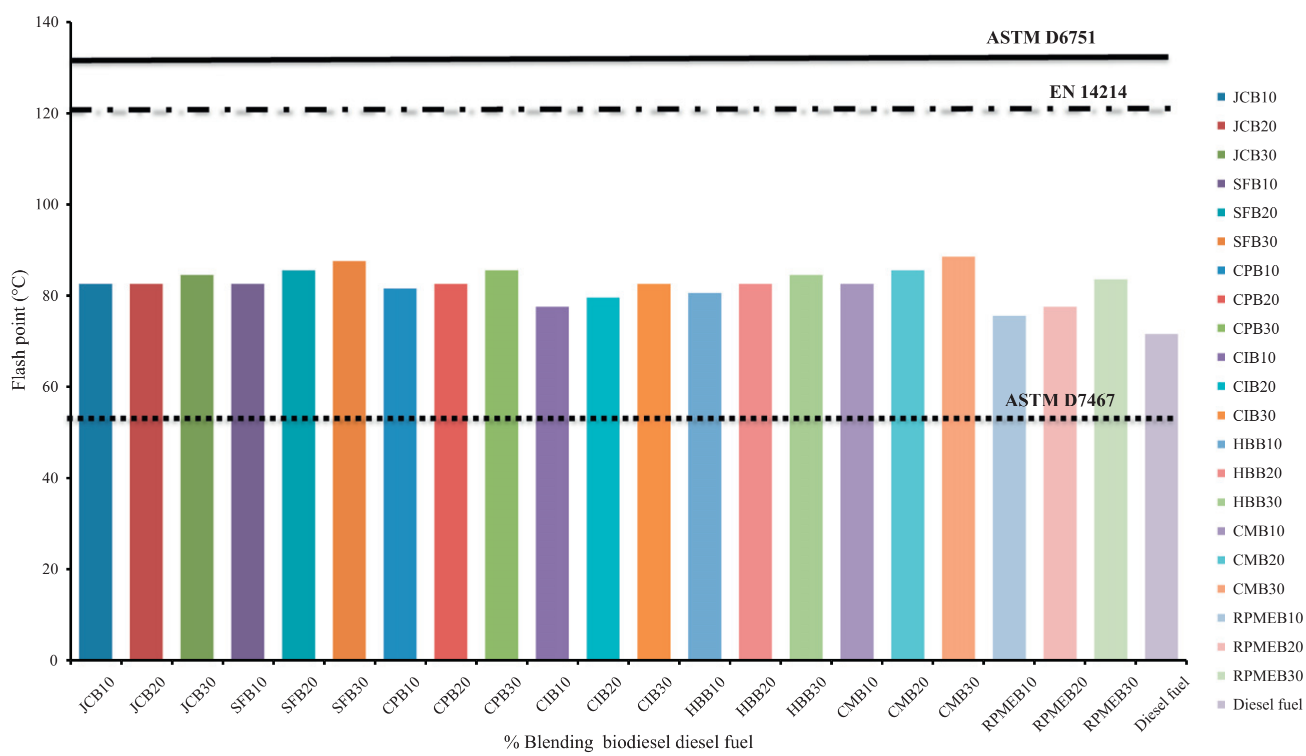


Fig. 5. Flash point of biodiesel diesel blends.

3.0 °C to 6.0 °C. It is shown that non edible biodiesel blends suitable to be used in tropical and temperate regions without freezing during storage. The pour point of fuel was influenced by double bond chain and it is evidenced that pour point has higher unsaturated chain than saturated chain [20,25,42]. Hokment et al. [97] reviewed that the pour point of biodiesel is higher than diesel fuels due to biodiesel consists higher amount of saturated fatty acids. Therefore, one of the solutions to overcome the low-temperature problems of biodiesel is to blend with diesel fuel. JCME, CIME, CPME, HBME and CMME were classified as an unsaturated oil due to the presence of oleic and linoleic acids [20,22,24,42].

6.5. Biodiesel diesel blend cloud point

The cloud point is the temperature at which components of the fuel begin to crystallize and forming a visible clouding of the liquid. Fig. 7 shows that cloud point for RPMEB at 10%, 20% and 30%v/v were 6.0 °C, 8.0 °C and 10.0 °C, respectively. Besides, pour point for CIB, CMB and JCB were higher compared to CPB, HBB and SFB. The trend of cloud point for biodiesel diesel blends was increased by increasing the biodiesel blending ratio. However, RPME blends exhibited highest cloud point values at each blend ratio. It can be seen that biodiesel diesel blends have lower cloud point (< 5 °C) except for RPME which is between 6.0 °C and 10.0 °C. Therefore, palm biodiesel is not suitable to be used in cold weather countries [4]. This agrees with Sarin et al. [112]

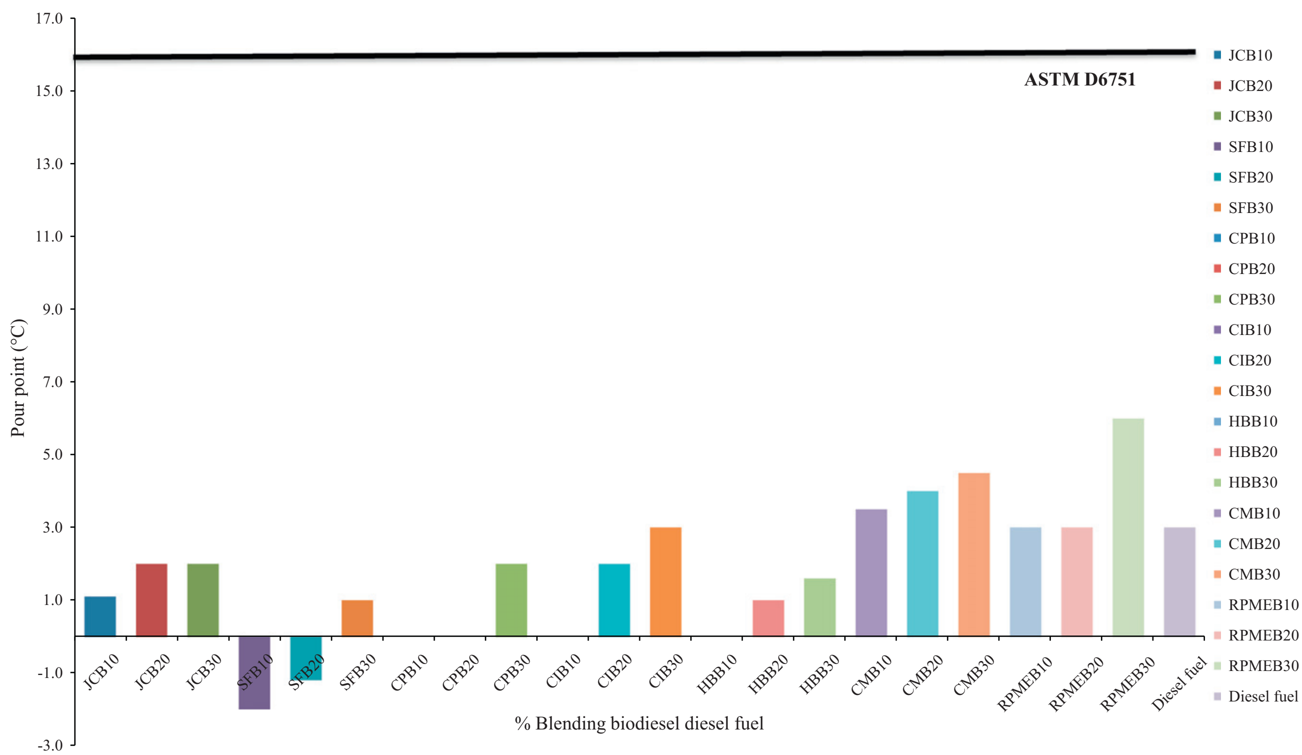


Fig. 6. Pour point of biodiesel diesel blends.

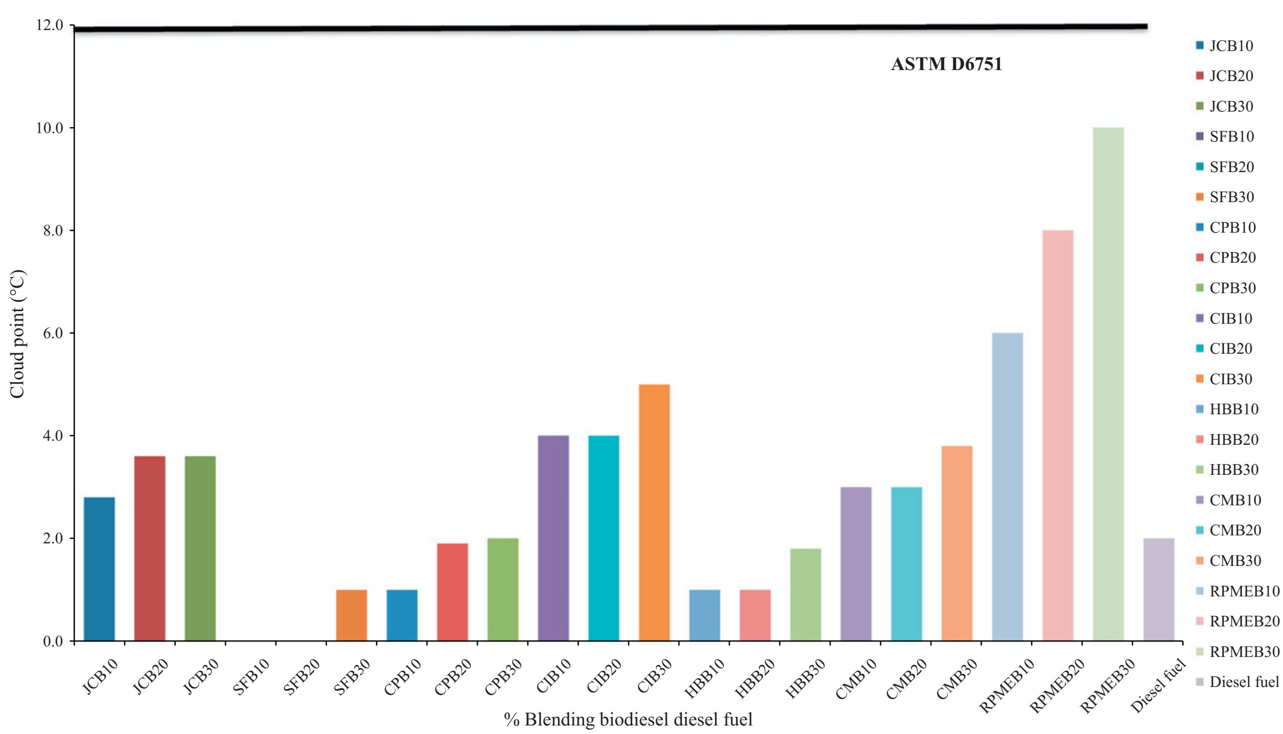


Fig. 7. Cloud point of biodiesel diesel blends.

which stated that *J. curcas* and *P. pinnata* biodiesel diesel blends have higher cloud point temperature than palm biodiesel. It is noticed that palm methyl ester is dominant by saturated chain (palmitic acid and stearic acid) which lead to lower cloud point [20]. However, Joshi and Pegg [113] investigated that cloud point of biodiesel diesel found decreased with biodiesel concentration and by addition of pour point depressants.

6.6. Biodiesel diesel blend oxidation stability

Oxidation occurs when the presence of unsaturated fatty acid chains and the double bond in the parent molecule which will immediately react with the oxygen as soon as being exposed to air [1,85,87]. The oxidation stability of B10, B20 and B30 for all blends was shown in Fig. 8. The study revealed that petrol–diesel

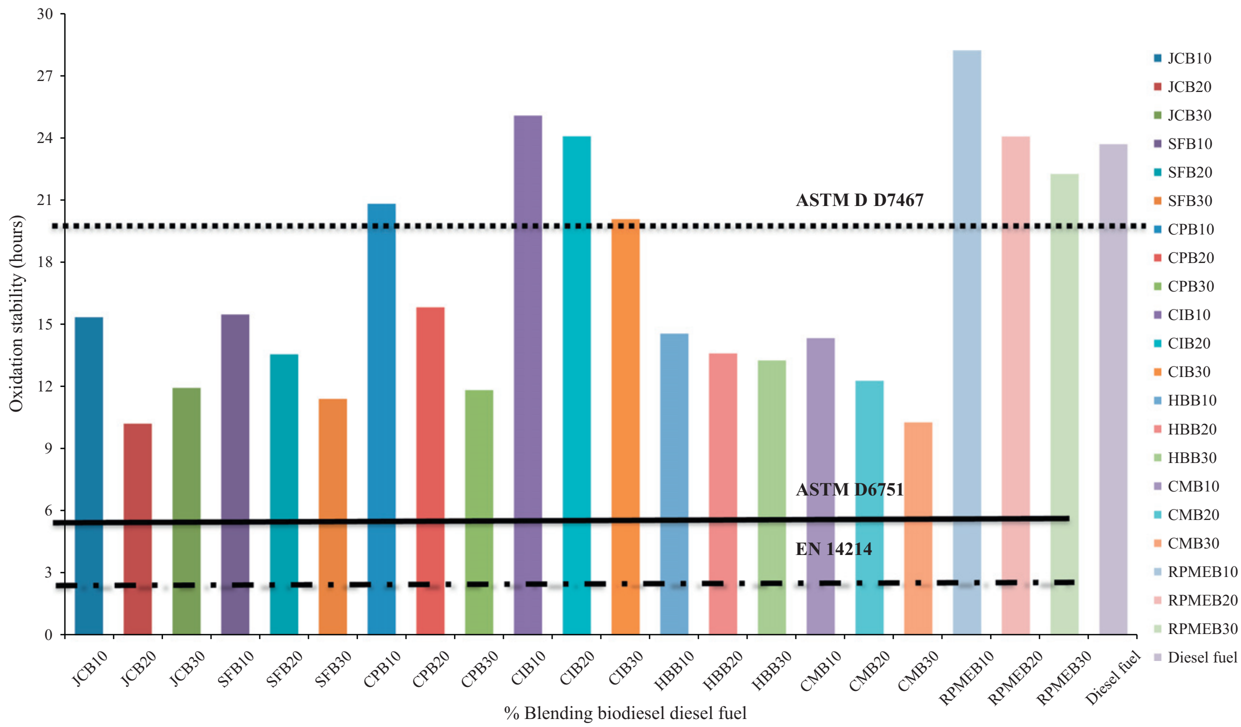


Fig. 8. Oxidation stability of biodiesel diesel blends.

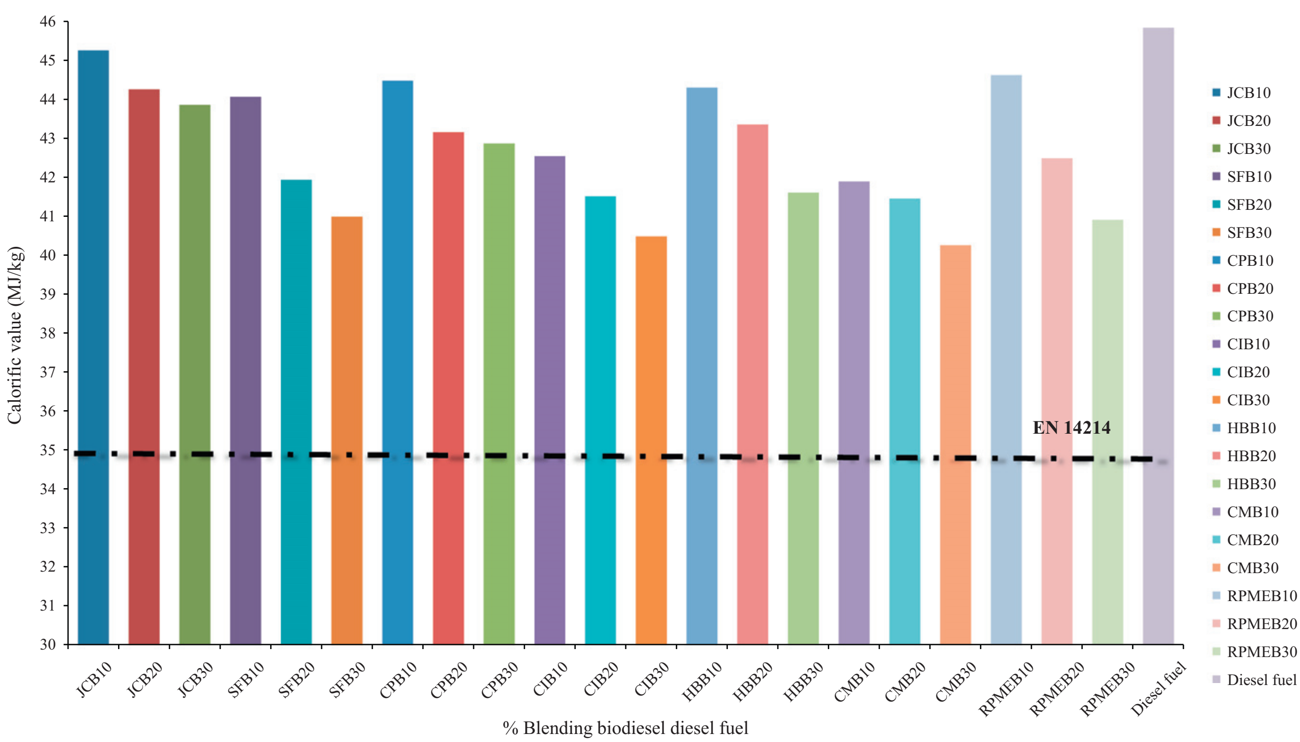


Fig. 9. Calorific value of biodiesel diesel blends.

had a strong impact on oxidation stability which the minimum induction period is 10 h. Moreover, the oxidation stability of B20 and B30 for all biodiesel diesel blends was lower than B10. This phenomenon may be attributed to the presence of double bond in non-edible oil affects the degree of aging fairly linearly for biodiesels [20,42,114–116]. Chakraborty and Baruah [117] stated that unsaturated fatty acid is significantly more prone to oxidation than saturated compounds. On other hand, Karavalakis et al. [118] mentioned that the stability of the biodiesel blends was affected by a variety of factors, including the composition of biodiesel, the presence of antioxidant additives and stage of oxidation.

6.7. Biodiesel diesel blend calorific value

Calorific value is the amount of heating energy released by the combustion of a unit value of fuels. The calorific value biodiesel diesel blends was slightly higher than biodiesel but lower than diesel fuel. From the results presented in Fig. 9, the calorific value of biodiesel ranges from 40.24 MJ/kg to 44.16 MJ/kg which is slightly lower than diesel which is 45.825 MJ/kg. The calorific value of fuel is the largest factor in the fuel economy, torque and power deliverability. The calorific value of the biodiesels increase marginally as the volume of biodiesel in the blend reduces. However, JCB10 and RPMEB10 have higher calorific value than other blending. This is as a result of the lower oxygen content of *J. curcas* and palm oil compared to other seed oils. Oghenejoboh and Umukoro [119] investigated that the presence of oxygen in fuel will improve the combustion properties and emissions but reduces the calorific value. Another disadvantage caused by low calorific value is high carbon residue in the combustion engine chamber [90].

7. Conclusion

The potential biodiesel feedstocks are reviewed and physicochemical parameters were measured according to ASTM and EN standards. Most of the analyzed biodiesel properties results were closer to diesel fuel. There are few biodiesel samples not meeting the standard but it did not significantly affect to the performance of fuel properties. Thus, biodiesel can be considered as feasible alternative substitution fuel for diesel engine without any modification. Conversely, the biodiesel enrichment caused an increase in viscosity and reduces the volatility of the blends. Therefore, further study on utilization of biodiesel in diesel engine need to be carried out in order to assure optimization in engine operation.

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